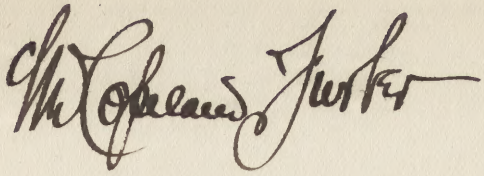
CORPS OF ENGINEERS, U. S. A.

REPORT
OF
BOARD OF ENGINEER OFFICERS
ON
TESTING HYDRAULIC CEMENTS
WITH
SPECIFICATIONS FOR THE SEVERAL CLASSES
USED BY
THE ENGINEER DEPARTMENT



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No. 28

REPORT

OF

Board of Engineer Officers

ON

Testing Hydraulic Cements

WITH SPECIFICATIONS FOR THE SEVERAL CLASSES USED BY THE ENGINEER DEPARTMENT

MAJOR WILLIAM L. MARSHALL
MAJOR SMITH S. LEACH
CAPTAIN SPENCER COSBY
} *Corps of Engineers, U. S. Army, Members of the Board*

SECOND EDITION

CHICAGO
HOLLISTER BROTHERS, PRINTERS
1903

CEMENT DEPARTMENT
Illinois Steel Company
"THE ROOKERY"
CHICAGO
EDWARD M. HAGAR, MANAGER

Chicago, Sept. 26, 1901.

Mason M. Patrick, Capt.,

Corps of Engineers, U.S.A.,

Washington, D.C.

Dear Sir:

I wish to thank you for your favor of the 21st inst., and the five copies of Professional Papers No.28, being the Report of the Board of Engineer Officers on Testing Hydraulic Cements.

I regret to note, however, that you cannot favor me with more than this number of copies, and as I find that we could make most excellent use of a much larger number of these reports, I would respectfully request permission for this company to reprint the same at our own expense.

We feel sure that nothing but good can come from the widest possible dissemination of this able paper. You will note from the above letter head that we have already changed the name from "Steel Portland Cement" to "Steel Puzzolan Cement", in conformity with the classification given therein.

Trusting that my request may be granted, I remain,

Yours very truly,

Edward M Hagar

Dic. E.M.H.

Manager.

WAR DEPARTMENT,

WASHINGTON,

October 4, 1901.

Sir:

Referring to your letter of 26th ultimo, addressed to Captain Mason M. Patrick, Corps of Engineers, in which you acknowledge the receipt of his letter of 21st ultimo, with five copies of Professional Papers No.28, being Report of the Board of Engineer Officers on Testing Hydraulic Cements, and request permission to reprint a number of copies, I beg to inform you that the War Department will interpose no objection to the reprinting of said paper, provided the same is reprinted as a whole; that the publication be not copyrighted, and that proof thereof be sent to the Chief of Engineers, U.S. Army, before the final print is made.

Very respectfully

Acting Secretary of War.

Mr Edward M. Hagar,
Manager Cement Department,
Illinois Steel Company,
The Rookery,
Chicago, Illinois.

76285

OFFICE OF THE CHIEF OF ENGINEERS,
UNITED STATES ARMY,
Washington, August 13, 1902.

SIR: Under date of June 19, 1901, authority was granted this office by the Secretary of War to publish a report of a Board of Engineer Officers on Testing Hydraulic Cements, copy herewith. This report has proven of great value to the engineering profession at large. The edition of 1,000 copies printed has been exhausted, and the demand for the volume still continues.

Maj. W. L. Marshall, Corps of Engineers, president of the Board, has submitted a memorandum of corrections and additions to the report recommended by him.

In view of the demand still existing for copies of this report, it is recommended that 1,000 additional copies of the report, with the changes suggested by Major Marshall, be printed at the Government Printing Office and furnished for the use of this office on the customary requisition.

Very respectfully, your obedient servant,

G. L. GILLESPIE,
Brig. Gen., Chief of Engineers,
U. S. Army.

Hon. ELIHU ROOT,
Secretary of War.

(First indorsement.)

Approved as within recommended by the Chief of Engineers.

W. SANGER,
Acting Secretary of War.

WAR DEPARTMENT, *August 15, 1902.*

OFFICE OF THE CHIEF OF ENGINEERS,
UNITED STATES ARMY,
Washington, June 11, 1901.

SIR: I have the honor to transmit herewith a report of a Board of Officers, convened under your authority by Special Orders, No. 56, Headquarters Corps of Engineers, 1900, to consider and report upon the general subject of manipulating and testing hydraulic cements used in the public works carried on under the supervision of this office.

The Board has given the subject careful study, and its report, which is accompanied by a proposed draft of specifications, is recommended for approval with a view of securing uniform practice as far as possible throughout the Engineer Department.

As the report contains much information that is valuable, not only to the Corps of Engineers, but also to the engineering profession at large, I further recommend that 1,000 copies be printed at the Government Printing Office and furnished for the use of this office on the customary requisition.

Very respectfully, your obedient servant,

G. L. GILLESPIE,
Brig. Gen., Chief of Engineers,
U. S. Army.

Hon. ELIHU ROOT,
Secretary of War.

(First indorsement.)

Approved as within recommended.

By order of the Secretary of War:

JOHN C. SCOFIELD,
Chief Clerk.

WAR DEPARTMENT, *June 19, 1901.*

Letter of Instructions

HEADQUARTERS, CORPS OF ENGINEERS,
UNITED STATES ARMY,

Washington, December 17, 1900.

MAJOR: In view of the lack of uniformity that exists in the specifications for cements submitted to this office for approval, it is considered desirable that a uniform set of specifications for each class of cement should be prescribed for use in works under the supervision of this office.

The Board will therefore consider the general subject of testing cements and make such recommendations on that subject as will be applicable under the conditions prevailing on the works carried on under the supervision of officers of the Corps of Engineers.

The Board in its report will follow in a general way the report of the Board on Electrical Installations, recently submitted, and, after its remarks and recommendations, will include as appendixes to the report sets of standard specifications for both Rosendale and American Portland cements which shall embrace all the requirements necessary to secure a suitable cement.

It is not expected that the Board will introduce unnecessary refinements in the tests required, but will bear in mind the actual conditions that obtain in the

Engineer Department. It is desired, however, that the report be complete and authoritative along the line suggested.

The subject of slag cements has recently been reported on by a Board of Engineer Officers, but without any recommendations as to the conditions under which they may safely be used. The Board is therefore requested to consider this subject, and if in its judgment their use is considered admissible, it is requested to state such conditions and to prepare a set of standard specifications for slag cements.

In view of the possible economy resulting to the Government from its grinding together cement and silica sand, it is requested that this subject be also given consideration by the Board.

The Board is authorized to call upon the district engineer officers for such records of tests or such other information as may be available.

Very respectfully,

JOHN M. WILSON,
Brig. Gen., Chief of Engineers.
U. S. Army.

Maj. W. L. MARSHALL,
Corps of Engineers,
President of Board on Specifications for Cements,
New York City.

Report

United States Engineer Office,

New York City, June 6, 1901.

General: The Board of Officers of the Corps of Engineers, constituted by Special Orders, No. 56, Headquarters Corps of Engineers, December 17, 1900, has the honor to submit the following report:

The Board convened at the Army Building, in New York City, upon the call of the senior member, at 10 a. m., January 8, 1901, all the members of the Board being present. At sessions held on that and the following day the Board arrived at a substantial agreement upon the leading points of the subject referred to it, and upon the general wording of the specifications for the several classes of cement, and then adjourned to meet at the call of the senior member for the completion of the report.

Under the authority of Special Orders, No. 3, Headquarters Corps of Engineers, January 12, 1901, the Board reconvened in New York City, at the call of the senior member, at 10 a. m., March 28, 1901. During a session of that day the views of the several members, presented in writing, were carefully considered,

and the Board agreed upon a report and specifications. An April 2 these were sent to the Chief of Engineers, but were returned to the Board with the request that it consider the additional subjects of sampling the cement, amount of testing desirable depending on the importance of the work and the size of the order and the records that should be kept.

At the call of the senior member, and by authority of Special Orders, No. 20, Headquarters Corps of Engineers, May 15, 1901, the Board reassembled in New York City at 10 a. m., May 29, and formulated its report upon the additional subjects referred to it, the members having previously communicated their views to one another in writing. The additional subjects have been incorporated in the following report, which is accompanied by three sets of proposed specifications.

GENERAL CONSIDERATIONS.

The constructing engineer is confronted by no problem more difficult than to decide whether a certain cement, when placed in a work, will behave in a predetermined way. This is especially true of Portlands. Other cements are much more reliable under conditions of exposure for which they are suited.

The difficulties arise from the fact that tests for acceptance or rejection must be made on a product

not in its final stage. A cement, when incorporated in masonry, undergoes for months chemical changes in the process of setting, so that the material subjected to strains in the work is not the material tested, but a derivative of it. The object of tests is to establish two probabilties: First, that the product of the given cement will develop the desired strength and hardness soon enough to enable it to bear the stresses designed for it; second, that it will never thereafter fall below that strength and hardness. Up to the present time it appears that the relation between the chemical and physical properties of raw cement and of its partially indurated derivatives, determined by tests, and the physical properties of the same cement or its derivatives, after complete hydration and induration in the work, can be stated only within rather wide limits.

The most useful tests of cements are those, first, which connect themselves definitely with some serious defect to which cements are subject, or with some merit which they should possess; second, which can be made with the least apparatus and manipulation, and which give their indications in the shortest time; and, third, which are freest from personal equation and from influences of local surroundings. These criteria, applied to the customary tests of cements, give indications as to their relative value and the best methods of making them.

TEST OF GRINDING.

This test derives importance from the fact, apparently well established, that, other things being equal, the finer the cement the greater will be its sand-carrying capacity; that is, it will show greater strength with the same charge of sand, or equal strength with a greater charge. According to the best information the Board can obtain, the cementitious value of this material is believed to reside principally, if not wholly, in the very fine part. It follows that a grinding test should be directed to determining the proportion which is very fine rather than the residue above a certain size. The Board does not propose any change in the accepted grinding test of Portland cement, but favors for Natural cement the use of the same size screen as for Portland, No. 100, with the requirement that 80 per cent shall pass through it. The screen should be frequently examined, magnified, if practicable, to see that no wires are displaced leaving apertures larger than the normal.

TEST FOR SPECIFIC GRAVITY.

This test is made with simple appliances, and its result is immediately known. It appears to connect itself quite definitely with the degree of calcination which the cement has received. The higher the burning,

short of vitrification, the better the cement and the higher the specific gravity.

This test has another value, in that the adulterations of Portland cement most likely to be practiced and most to be feared are made with materials which reduce the specific gravity. The test is therefore of value in determining a properly burned, nonadulterated Portland. If underburned, the specific gravity may fall below 3; it may reach 3.5 if the cement has been overburned. No other hydraulic cement is so heavy in proportion to volume, Natural cement having a specific gravity of about 2.5 to 2.8 and Puzzolan (slag) of about 2.7 to 2.8. Properly burned Portland, adulterated with slag, will fall below 3.1.

TEST OF ACTIVITY.

This test, made by gauging the cement with water and observing the times of initial and permanent set, is partly direct and partly indirect. It is direct in so far as its limits relate to the time necessary to get the cement in place after mixing, which must not be greater than the time of initial set, and to the time within which the cement product must take its load, which must not be less than the time of permanent set. It is indirect in so far as its limits relate to the probable final strength, elasticity and hardness of the cement mixtures. In the latter respect it appears to be

reasonably well established that cements exhibiting great activity give, after long periods, results inferior to those with action less rapid.

The test for activity is easily made with simple appliances, and its results are known in a few hours at most. Variable results in the test are caused by different local conditions of moisture and temperature and by the different judgments of observers as to whether the needles penetrate or not. Generally speaking, both periods of set are lengthened by increase of moisture and shortened by increase of temperature. Some manufacturers claim that their cements show their best results when gauged with particular percentages of water. It is not considered good policy to encourage these peculiarities at the expense of the uniformity of tests which is so greatly desired. It is better to adopt a definite proportion of water for gauging and require all cements of the same class to stand or fall on their showing when so gauged. Such a percentage, adopted and known, will probably be used by manufacturers in testing goods sold to the Engineer Department, and a greater harmony between mill and field tests of the same cement will result.

In gauging Portland cement the samples should be thoroughly dried before adding water. This precaution is not deemed necessary with Natural cement. Sufficient uniformity of temperature will result if the

testing room be comfortably warmed in winter and the specimens be kept out of the sun in a cool room in summer, and under a damp cloth until set.

TEST FOR CONSTANCY OF VOLUME.

This test results from observations made on the pats or cakes used in the setting test. It derives its value from its connection with the quantity of expansives in the cement.

The test is easy to make, and its results are relatively free from personal error, though there is room for a difference of judgment as to the appearance of the cakes. As they may be preserved and the decision reviewed at any time on the original data, such differences are immaterial.

TESTS OF STRENGTH.

These may be subdivided into compressive and tensile tests, the latter including the transverse test made by breaking a beam of the cement. The compressive test need not be further considered, as it is less easily made than the tensile test and gives no surer indications. The ratio of compressive to tensile strength of the same class of cements is quite uniform.

Of the tensile tests the direct pull is preferable to the flexure test.

The tensile test is theoretically a perfect index of the quality of the cement at the periods of test, and a

comparison at different periods gives the best obtainable indication of what its subsequent conduct will be. In the opinion of the Board the two periods most generally adopted, seven and twenty-eight days after mixing, are, on the whole, the best. The one-day test, though of some value in a discriminating sense, should not be placed in the same category as the other periods named.

The apparatus for tensile tests is somewhat elaborate and delicate, but is of standard manufacture and readily obtainable at relatively small cost.

In respect of uncertainties due to the personal equation of the tester and to the influence of local conditions this test presents greater difficulties than any of the others considered. The most scrupulous care must be observed in the manipulations, and the tester should possess natural aptitude for such work. The object is to determine the greatest stress per square inch which the cement can be made to stand under given conditions without rupture. If the conditions have been carefully observed and several discrepant results are obtained, the highest may be right, but the others are certainly wrong. No averaging should be done.

The remarks made above under the activity test as to the relation between early hydraulic intensity and the final excellence of a cement product are equally applicable to the indications from tensile tests. A

cement which sets moderately high at seven days and shows a substantial increase to twenty-eight days is more likely to reach the maximum strength slowly and retain it indefinitely with a low modulus of elasticity than a cement which tests abnormally high at seven days with little or no increase at twenty-eight days.

ACCELERATED TESTS.

The rules recommended by the committee of the American Society of Civil Engineers in 1885 have been substantially accepted here and abroad as to tests of setting qualities and soundness; more rapid tests for soundness, are, however, proposed and practiced, though no accelerated test has been generally accepted.

Accelerated tests proposed for the speedy detection of the presence of expansives in cement usually consist in the application, after gauging, of dry heat or of immersion in warm or boiling water or steam. The immersion tests are most in vogue. They vary from immersing freshly gauged pats on glass plates in water at 115 degrees F. for twenty-four hours, or at higher temperatures for various periods, to steaming or boiling cakes or cylinders of the material to be tested at 212 degrees F. for varying times.

In France and Germany the swelling or expansion of boiled cylinders is measured directly by calibration. Usually change of volume not accompanied by visible

evidences of it—i. e., distortion or disruption—is not observed in American tests prescribed in specifications for the reception of cements. Of all these tests the boiling test is the simplest, requires only apparatus everywhere available, and is recommended by the Board. It has been the experience that this test detects material that is unsound by reason of the presence of active expansives; but in some cases it rejects material that would give satisfactory results in actual work and will reject material that would stand this test after air slaking.

The great value of the test lies in its short-time indications and in at once directing attention to weak points in the cement to be further observed or guarded against. Of two or more cements offered for use or on hand the cements that stand the boiling tests are to be taken preferably; it should be constantly applied on the work among other simple tests to be noted, for although the boiling test sometimes rejects suitable material it is believed that it will always reject a material unsound by reason of the existence of active expansives. Sulphate of lime, while enabling cements to pass the boiling tests, introduces an element of danger.

This test is proposed as suggestive or discriminative only. Except for works of unusual importance it is not recommended that a cement passing the other tests proposed shall be rejected on the boiling test.

TESTS TO BE MADE.

For selecting Portland and Puzzolan cement from among the brands offered, the Board recommends that the following tests be made:

1. For fineness of grinding.
2. For specific gravity.
3. For soundness, or constancy of volume in setting.
4. For time of setting.
5. For tensile strength.

For Natural cement we recommend the omission of the specific gravity and soundness tests.

On the works the Board recommends simple tests when the more elaborate tests can not well be made.

In determining the minimum requirements for cements given in the subjoined specifications we recognize that many cements that attain only fair strength neat and with sand in a short time and show marked gains of strength on further time will fulfill the requirements of the service, and that unusually high tensile strength attained in a few days after gauging is often coupled with a small or negative increase in strength in further short intervals. Unusually high tests in a short time after gauging should be regarded with suspicion, although some well-known brands of American cements show great strength in short-time tests and, so far as observed, are reliable in air and

fresh water. Cements offered under such known brands should show their characteristic strength and other qualities or be suspected as spurious or adulterated if not rejected, even though the minimum requirements of the specifications are met. The practice of offering a bonus or free gift of money in addition to the contract price for cement testing above a fixed high point should be prohibited as unnecessary, for cements so obtained are likely to be unsound in a manner not easily detected in the time usually available in testing.

It is believed that most of the very high testing Portland cements have lime in excess, the effect of which is temporarily masked by the use of sulphate of lime. Overlimed cements so treated are unfit for use in sea water. For such uses a chemical analysis should be required and the quantity of sulphuric acid, as well as magnesia be limited to a low percentage.* It is not yet known that sulphate of lime in quantity less than 2 per cent is injurious to cements to be used in fresh water or in air. It masks expansives that might ultimately cause the destruction of the work, but it is not known whether this effect is permanent. Its addition is now deemed necessary to control time of setting.

*Not more than 3 per cent, by weight, of magnesia, 1 per cent of sulphate anhydride, or 2 per cent of sulphate of lime, should be allowed in any case. In sea water not exceeding one-half these quantities.

It makes a quick-setting cement slow setting, at the same time increasing tensile strength acquired in short time.

MANIPULATION OF CEMENTS FOR TESTS.

I. FINENESS.

Place 100 parts (denominations determined by subdivisions of the weighing machine used) by weight on a sieve with 100 holes to the linear inch, woven from brass wire No. 40, Stubb's wire gauge; sift by hand or mechanical shaker until cement ceases to pass through.

The weight of the material passing the sieve plus the weight of the dust lost in air, expressed in hundredths of the original weight, will express the percentage of fineness. In order to determine this percentage the residue on the sieve should be weighed.

It is only the impalpable dust that possesses cementitious value. Fineness of grinding is therefore an essential quality in cements to be mixed with sand. The residue on a sieve of 100 meshes to the inch is of no cementitious value, and even the grit retained on a sieve of 40,000 openings to the square inch is of small value. The degree of fineness prescribed in these specifications (92 per cent) for Portland through a sieve of 10,000 meshes to the square inch is quite commonly attained in high-grade American cements, but rarely

in imported brands. On the Pacific coast, where foreign cements mainly are in the market, this requirement may be lowered for the present to 87 per cent on No. 100 sieve.

II. Specific gravity.

The standard temperature for specific gravity determinations is 62 degrees F., but for cement testing temperatures may vary between 60 and 80 degrees F. without affecting results more than the probable error in the observation.

Use any approved form of volumenometer or specific gravity bottle, graduated to cubic centimeters with decimal subdivisions. Fill instrument to zero of the scale with benzine, turpentine, or some other liquid having no action upon cements.

Take 100 grams of sifted cement that has been previously dried by exposure on a metal plate for twenty minutes to a dry heat of 212 degrees F., and allow it to pass slowly into the fluid of the volumenometer, taking care that the powder does not stick to the sides of the graduated tube above the fluid and that the funnel through which it is introduced does not touch the fluid.

Read carefully the volume of the displaced fluid to the nearest fraction of a cubic centimeter. Then the

approximate specific gravity will be represented by 100 divided by the displacement in cubic centimeters.

The operation requires care.

III. Setting qualities and soundness.

The quantity of water and the temperature of water and air affect the time of setting. The specifications contemplate a temperature varying not more than 10 degrees from 62 degrees F., and quantities of water given herein:

For Portland cements use about 20 per cent of water.

For Puzzolan cements use about 18 per cent of water.

For Natural cements use about 30 per cent of water.

These quantities are for the cements as taken from the packages.

Mix thoroughly for five minutes, vigorously rubbing the mixture under pressure; time to be estimated from moment of adding water and to be considered of importance.

Make on glass plates two cakes from the mixture about three inches in diameter, half an inch thick at the middle, and drawn to thin edges, and cover them with a damp cloth or place them in a tight box not exposed to currents of dry air. At the end of the time specified for initial set apply the needle one-twelfth of an inch diameter weighted to one-fourth of a pound to one of

the cakes. If an indentation is made the cement passes the requirement for initial setting, if no indentation is made by the needle it is too quick setting. At the end of the time specified for "final set" apply the needle one twenty-fourth of an inch diameter loaded to one pound. The cement cake should not be indented.

Expose the two cakes to air under damp cloth for twenty-four hours. Place one of the cakes, still attached to its plate, in water for twenty-eight days; the other cake immerse in water at about 70 degrees temperature supported in a rack above the bottom of the receptacle; raise the water gradually to the boiling point and maintain this temperature for six hours and then let the water with cake immersed cool. Examine the cakes at the proper time for evidences of expansion and distortion. Should the boiled cake become detached from the plate by twisting and warping or show expansion cracks the cement may be rejected, or it may await the result of twenty-eight days in water. If the fresh-water cake shows no evidences of swelling, the cement may be used in ordinary work in air or fresh water for lean mixtures. If distortion or expansion cracks are shown on the fresh-water cake the cement should be rejected.

Of two or more cements offered, all of which will stand the fresh-water cake test for soundness, the cements that will stand the boiling tests also are to be preferred.

IV. Tensile strength.

Neat tests.—Use thoroughly dried unsifted cements.* Place the amount to be mixed on a smooth, nonabsorbent slab; make a crater in the middle sufficient to hold the water; add nearly all the water at once, the remainder as needed; mix thoroughly by turning with the trowel and vigorously rub or work the cement for five minutes.

Place the mold on a glass or slate slab. Fill the mold with consecutive layers of cement, each when rammed to be one-fourth of an inch thick. Tap each layer 30 taps with a soft brass or copper rammer weighing one pound and having a face three-fourths of an inch diameter or seven-tenths of an inch square with rounded corners. The tapping or ramming is to be done as follows: While holding the forearm and wrist at a constant level, raise the rammer with the thumb and forefinger about half an inch and then let it fall freely, repeating the operation until the layer is uniformly compacted by 30 taps.

This method is intended to compact the material in a manner similar to actual practice in construction,

*The hot clinker is often suddenly chilled by steam or water in order to reduce the work of grinding by first cracking it. This water, as well as that absorbed from the air, should always be expelled or its percentage ascertained and deducted from the amounts prescribed for briquettes. Sand, also, should be similarly treated.

when a metal rammer is used weighing 30 pounds, with circular head five inches in diameter falling about eight inches upon layers of mortar or concrete three inches thick. The method permits comparable results to be obtained by different observers.

After filling the mold and ramming the last layer, strike smooth with the trowel, tap the mold lightly in a direction parallel to the base plate to prevent adhesion to the plate, and cover for twenty-four hours with a damp cloth. Then remove the briquette from the mold and immerse it in fresh water, which should be renewed twice a week for the specified time if running water is not available for a slow current. If molds are not available for twenty-four hours, remove from the molds after final set, replacing the damp cloth over the briquettes. In removing briquettes before hard-set great care should be exercised. Hold the mold in the left hand and, after loosening the latch, tap gently the sides of the mold until they fall apart. Place the briquettes face down in the water trough.

For neat tests of Portland cement use 20 per cent of water by weight.

For neat tests of Puzzolan cement use 18 per cent of water by weight.

For neat tests of Natural cement use 30 per cent of water by weight.

Nearly all this water is retained by Portland cement, whereas only about one-third of the gauging water is retained by Puzzolan or Natural cements; from this it follows that an apparent condition of plasticity or fluidity that ultimately little injures Portland paste, very seriously injures Puzzolan or Natural mortars and concretes by leaving a porous texture on the evaporation of the surplus water.

Sand tests.—The proportions 1 cement to 3 sand are to be used in tests of Puzzolan and Portland, and 1 cement to 1 sand in tests of Natural or Rosendale cements. Crushed quartz sand, sifted to pass a standard sieve with 20 meshes per linear inch and to be retained on a standard sieve with 30 meshes to the inch, is to be used.

After weighing carefully mix dry the cement and sand until the mixture is uniform, add the water as in neat mixtures, and mix for five minutes by triturating or rubbing together the constituents of the mortar. This may be done under pressure with a trowel or by rubbing between the fingers, using rubber gloves. The rubbing together seems necessary to coat thoroughly the facets of the sand with the cement paste.

It is found that prolonged rubbing, when not carried beyond the time of initial set, results in higher tests. Five minutes is the time of mixing quite generally

adopted in European specifications. The briquettes are to be made as prescribed for neat mixtures.

Portland cements well dried require water from 10 to 12½ per cent by weight of constituent sand and cement for maximum ultimate strength in tested briquettes.

Puzzolan, about 9 to 10 per cent.

Natural, about 15 to 17 per cent.

Mixtures that at first appear too dry for testing purposes often become more plastic under the prolonged working required herein.

In general about four briquettes constitute the maximum number that may be made well within the time required for initial setting of moderately slow-setting cements.

Three such batches of sand mixtures should be made and one briquette of each batch may be broken at seven and twenty-eight days, giving three tests at each period. At least one batch of neat cement briquettes should be made.

If the first briquette broken at each date fulfills the minimum requirement of these specifications it is not necessary to break others which may be reserved for long-time tests.

If the first briquette does not pass the test for tensile strength then briquettes may be broken until six briquettes, two from each batch, have been broken at

seven days, and the remaining six reserved for twenty-eight-day tests. The highest result from any sample is to be taken as the strength of the sample when the break is at the least section of briquette.

If, on the twenty-eight-day tests, the cement not only more than fulfills the minimum requirements of these specifications, but also shows unusual gain in strength, it may still be accepted if the other tests are satisfactory, notwithstanding a low seven-day test, if early strength is not a matter of importance. Such cements are likely to be permanent.

For a batch of four briquettes, the following quantities are suggested as in accord with these specifications. Water is measured by fluid-ounce volumes, not by weight, temperature varying not more than 10° from 62° F.

PORTLAND CEMENT.

Neat: 20 ounces of cement, 4 ounces of water. Mix wet five minutes.

Sand: 15 ounces sand, 5 ounces cement, 2½ ounces water. Mix thoroughly dry; then mix wet five minutes.

PUZZOLAN CEMENT.

Neat: 20 ounces cement, 3¾ ounces water. Mix wet five minutes.

Sand: 15 ounces sand, 5 ounces cement, 2 ounces water. Mix thoroughly dry; then mix wet five minutes.

NATURAL CEMENT.

Neat: 20 ounces cement, 6 ounces water. Mix wet five minutes.

Sand: 10 ounces cement, 10 ounces sand, 3½ ounces water. Mix dry; then wet for five minutes.

For measuring tensile strength, a machine that applies the stress automatically at a uniform rate is preferable to one controlled entirely by hand.

These specifications for tensile strength contemplate the application of stress at the rate of 400 pounds per minute to briquettes made as prescribed herein. A rate so rapid as to approximate a blow or so slow as to approximate a continued stress will give very different results.

The tests for tensile strength are to be made immediately after taking from the water or while the briquettes are still wet. The temperature of the water during immersion should be maintained as nearly constant as practicable; not less than 50° nor more than 70° F.

The tests are to be made upon briquettes 1 inch square at place of rupture. The specifications contemplate the use of the form of briquette recommended by the committee of the American Society of Civil En-

gineers, held when tested by close-fitting metal clips, without rubber or other yielding contacts. The breaks considered in the tests are to be those occurring at the smallest section, 1 inch square.

SIMPLE TESTS.

Test of cement received upon a work in progress must often be of much simpler character than prescribed herein.

Tests on the work are mainly to ascertain whether the article supplied is genuine cement, of a brand previously tested and accepted, and whether it is a reasonably sound and active cement that will set hard in the desired time, and give a good, hard mortar. Simple tests may give this information, and such should be multiplied whether or not more elaborate tests be made. Pats and balls of cement and mortar from the storehouse and mixing platform or machine should be frequently made. The setting or hardening qualities, as determined roughly by estimating time and by pressure of the thumbnail, should be observed; the hardness of the set and strength, by cracking the hardened pats or cakes between the fingers, and by dropping the balls from the height of the arm upon a pavement or stone and observing the result of the impact.

By placing the pats in water as soon as hardened sufficiently and raising the temperature to the boiling

point for a few hours and observing the character and color of the fracture after sufficient immersion, information as to the character of the material, whether hydraulic, a Portland or Puzzolan, whether too fresh or possibly "blowy," may be speedily and quite well ascertained without measuring instruments.

Many engineers and users of cements regard such simple tests, taken in connection with the weight and fineness of the cement and the apparent texture and hardness of the mortars and concretes in the work, sufficient field tests of a material of known repute. The more elaborate tests, described above, should be made in well-equipped laboratories by skilled cement testers.

CLASSIFICATION OF TESTS.

The tests to be made are two classes.

(1) Purchase test on samples furnished by bidders to ascertain whether the bidder may be held on the sample to the delivery of suitable material, should his offer be accepted.

(2) Acceptance tests on samples taken at random from deliveries, to ascertain whether the material supplied accords with the purchase sample, or is suitable for the purpose of the work, as stated in the specifications for cement supplies.

(1) *Purchase tests.*—Under these specifications bids for Portland cements will be restricted to brands

that have been approved after at least three years' exposure in successful use under similar conditions to those of the proposed work. This specification limits proposals to manufacturers of cements of established repute, and in so far lessens the dependence to be placed upon tests of single samples of cement in determining the probable quality of the cements offered, that sample packages may not be required with the proposals when the brand is known to the purchaser. When the cement is not known to the purchasing officer by previous use, a barrel of it should be required as representing the quality of cement to be supplied. A full set of tests should be made from this sample, and subsequent deliveries be required to show quality at least equal to the sample.

In this connection it is advisable in districts where well-equipped laboratories have been established, that sample packages of the cements in use in that territory, as sold in the open market, be obtained and tested as occasion offers to ascertain the characteristic qualities of the brands as commercial articles, the information to be used in subsequent purchases of cements.

When purchase samples are waived, acceptance tests should be based upon the known qualities of the brand, as shown by previous tests.

The sample barrel should not be broken further than to take therefrom the necessary samples for testing.

Afterwards it should be put away in a dry place and kept for further testing, should the results obtained be disputed.

(2) *Acceptance tests.*—The tests to be made on cements delivered under contract depend not only on the extent, character and importance of the work itself, but also on the time available between the delivery and the actual use of the material.

(*a*) On very important and extensive works, equipped with a testing laboratory and adequate storehouses, where cement may be kept at least thirty days before being required for use, full and elaborate tests should be made, keeping in view the fact that careful tests of few samples are more valuable than hurried tests of many samples.

(*b*) On active works of ordinary character, when time will not permit full tests, and on small works where the expenses of a laboratory are not justified, the tests must necessarily be limited to such reasonable precautions against the acceptance and use of unfit material as may be taken in the usually short interval between the receipt and use of the material.

Such conditions were in view in formulating the specification that proposals will be received from manufacturers of such cements only as have been proved by at least three years' use under similar conditions of exposure. Of the tests named in the specifications

those for fineness, activity or hydraulicity, specific gravity, weight of packages, and accelerated tests for indications as to soundness, may be made within two days after the receipt of the material and with a very small outlay for instruments.

Cement of established repute, shown by specific gravity and fineness to be properly burnt and ground, or normal for the brand, that will set hard in reasonable time, the cakes snapping with a clean fracture when broken between the fingers, and standing the tests above named, may be accepted and used with reasonable certainty of success. Nevertheless, packages taken at random from the deliveries should occasionally be set aside and samples taken therefrom sent to a testing laboratory for the more elaborate tests for tensile strength (and for soundness should the boiling tests not be conclusive). The final acceptance and payment for such cement as may not have been actually placed in the work should, by agreement, be made to depend upon such tests.

In all cases where cement has been long stored it should be carefully tested before use to ascertain whether it has deteriorated in strength.

Should the simple tests give unsatisfactory or suspicious results, then a full series of tests should be carefully made.

When Portland cement is in question the specific gravity and fineness tests should be made to guard against adulteration, and in all cases test weighings should be made to guard against short weights.

In cases where the amount of cement or the importance of the work will not justify the purchase of the simple apparatus required for the specific gravity, fineness, and boiling tests, the cement can be accepted on the informal tests mentioned herein, which require no apparatus whatever, but in such cases cements well known to the purchaser by previous use should be selected, and purchased directly from the manufacturer or his selling agent in order that responsibility for the cement may be fixed.

Certified tests by professional inspectors made as prescribed herein on samples taken from the cement to be shipped to the work, in a manner analogous to that customary among engineers in the purchase of structural steel and iron, may be required in such cases.

SAMPLING.

The entire package from parts of which tests are to be made is to be regarded as the sample tested. It should be marked with a distinctive mark that must also be applied to any part tested. The package should be set aside and protected against deterioration until all results from tests made from it are reached and ac-

cepted by both parties to the contract for supplies.

Cement drawn from several sample packages should not be mixed or mingled, but the individuality of each sample package should be preserved.

In testing it should be borne in mind that a few tests from any sample, carefully made, are more valuable than many made with less care.

The amount of material to be taken for formal tests is indicated herein where weights of the constituents of four briquettes are given, to which should be added the amount necessary for the tests for specific gravity, activity, and soundness.

In extended tests the material should be taken from the sample package from the heads and center of barrel, and from the ends and center of bag, by such an instrument as is used by inspectors of flour. All material taken from the same sample package may be thoroughly mixed or mingled and the tests be made therefrom as showing the true character of the contents of the sample package.

In making formal tests at the work for acceptance of cement sample packages should be taken at random from among sound packages. The number taken must depend upon the importance and character of the work, the available time, and the capacity of the permanent laboratory force. For tensile strength the tests with

sand are considered the more important and should always be made. Tests neat should be made if time permits.

It is not necessary in any case on a large work to test more than 10 per cent of the deliveries, even of doubtful cement, and a much less number of samples may be taken should no cause for distrust be revealed by the tests made. In very important work of small extent each package may be tested. A cement should be rejected if the samples show dangerous variation in quality or lack of care in manufacture and resulting lack of uniformity in the product without regard to the proportion of failures among samples tested.

In all cases in the use of cements the informal or simple tests of the character named herein should be constantly carried on. These constitute most valuable tests. Whenever any faulty material is indicated by such tests, elaborate tests should be at once instituted and should the fault be confirmed, the cement delivered and not used should be rejected and the use of the brand be discontinued.

TESTS FOR WEIGHT.

From time to time packages should be weighed in gross and afterwards the weight of neat cement and tare of the packages determined. If short weight of neat cement is indicated, a sufficient number of pack-

ages should be weighed and the average net weight per package ascertained with sufficient certainty to afford a satisfactory basis of settlement.

RECORDS.

For tests at professional laboratories no general requirements as to records seem to be necessary. Each laboratory has its own blanks with certificate, and if a copy of the specifications be sent with the samples, the record returned should be sufficient. For records of formal tests on the work, or in a district laboratory, blank forms should be used. It is desirable to have the specification requirements stated on the form. Notations should be adopted to show for each test that the cement passed or failed or that the test was not made. No inference should be drawn from the lack of any entry other than that the recorder has neglected his duty.

SILICA CEMENT OR SAND CEMENT.

This is a patented article manufactured by grinding together silica or clean sand with Portland cement, by which process the original cementing material is made extremely fine and its capacity to cover surfaces of concrete aggregates is much increased. The sand is an adulteration, but on account of the extreme fineness of the product it serves to make mortar or concrete containing a given proportion of pure cement much

more dense, the fine material being increased in volume.

The increase in cementing capacity due to the fine grinding of the cement constituent offsets, in great degree, the effects of the sand adulteration, so that sand cement made from equal weights of cement and sand approximates in tensile strength to the neat cement and the material is sold as cement.

The extreme fine grinding also improves cement that contains expansives, but nevertheless sand cement should not be purchased in the market, but should be made on the work from approved materials, if used for other purposes than for grouting, for which it is peculiarly adapted.

Whether this material should be used in important works for mortar and concrete, the Board considers a question of cost and expediency.

Over against the saving in cement may be placed the royalty on a patented article, the cost of the plant and of manufacture, the inconvenience of attaching a manufacturing establishment to a work under construction, and other elements bearing not only on first cost of cementing material but also involving the element of time. When cement is high priced, means of transportation limited, labor, sand, and concrete materials cheap and abundant, the conditions may justify the use of sand cement on economic grounds. In any

case, the cement from which the product is made should be tested precisely as other cements.

SLAG CEMENT.

This term is applied to cement made by intimately mixing by grinding together granulated blast-furnace slag of a certain quality and slaked lime, without calcination subsequent to the mixing. This is the only cement of the Puzzolan class to be found in our markets (often branded as Portland), and as true Portland cement is now made having slag for its hydraulic base, the term "slag cement" should be dropped and the generic term *Puzzolan* be used in advertisements and specifications for such mixtures not subsequently calcined.

Puzzolan cement made from slag is characterized physically by its light lilac color; the absence of grit attending fine grinding and the extreme subdivision of its slaked lime element; its low specific gravity (2.6 to 2.8) compared with Portland (3 to 3.5); and by the intense bluish green color in the fresh fracture after long submersion in water, due to the presence of sulphides, which color fades after exposure to dry air.

The oxidation of sulphides in dry air is destructive of Puzzolan cement mortars and concretes so exposed. Puzzolan is usually very finely ground, and when not treated with soda sets more slowly than Portland. It stands storage well, but cements treated with soda to

quicken setting become again very slow setting from the carbonization of the soda (as well as the lime) element after long storage.

Puzzolan cement properly made contains no free or anhydrous lime, does not warp or swell, but is liable to fail from cracking and shrinking (at the surface only) in dry air.

Mortars and concretes made from Puzzolan approximate in tensile strength similar mixtures of Portland cement, but their resistance to crushing is less, the ratio of crushing to tensile strength being about 6 or 7 to 1 for Puzzolan and 9 to 11 to 1 for Portland. On account of its extreme fine grinding Puzzolan often gives nearly as great tensile strength in 3 to 1 mixtures as neat.

Puzzolan permanently assimilates but little water compared with Portland, its lime being already hydrated. It should be used in comparatively dry mixtures well rammed, but while requiring little water for chemical reactions, it requires for permanency in the air constant or continuous moisture.

PROPER USES OF PUZZOLAN CEMENT.

Puzzolan cement never becomes extremely hard like Portland, but Puzzolan mortars and concretes are tougher or less brittle than Portland.

The cement is well adapted for use in sea water, and generally in all positions where constantly exposed to

moisture, such as in foundations of buildings, sewers and drains, and underground works generally, and in the interior of heavy masses of masonry or concrete.

It is unfit for use when subjected to mechanical wear, attrition, or blows. It should never be used where it may be exposed for long periods to dry air, even after it has well set. It will turn white and disintegrate, due to the oxidation of its sulphides at the surface under such exposure.

Sulphuretted hydrogen, which is often evolved upon decomposition of the sulphides in Puzzolan cement, is injurious to iron and steel. Such metals, if used in connection with Puzzolan cement, should be protected, or an allowance be made for deterioration by an increase of section.

Specifications for Portland, Natural, and Puzzolan cement are appended hereto.

Respectfully submitted.

W. L. MARSHALL,
Major, Corps of Engineers.
SMITH S. LEACH,
Major, Corps of Engineers.
SPENCER COSBY,
Captain, Corps of Engineers.

Brig. Gen. G. L. GILLESPIE,
Corps of Engineers, U. S. Army,
Washington, D. C.

Specifications for American Portland Cement

(1) The cement shall be an American Portland, dry and free from lumps. By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, of argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product.

(2) The cement shall be put up in strong, sound barrels well lined with paper, so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not established itself as a high-grade Portland cement and has not for

three years or more given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade Portland cement which have been made by the same mill and in successful use under similar climatic conditions to those of the proposed work for at least three years.)

(5) The average weight per barrel shall not be less than 375 pounds net. Four sacks shall contain one barrel of cement. If the weight, as determined by test weighings, is found to be below 375 pounds per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, specific gravity, soundness, time of setting, and tensile strength of the cement.

(7) *Fineness.*—Ninety-two per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) *Specific gravity.*—The specific gravity of the cement, as determined from a sample which has been carefully dried, shall be between 3.10 and 3.25.

(9) *Soundness.*—To test the soundness of the cement, at least two parts of neat cement, as taken from the package, mixed for five minutes with about 20 per cent of water by weight shall be made on glass, each pat about 3 inches in diameter and one-half inch thick at the center, tapering thence to a thin edge. The pats are to be kept under a wet cloth until finally set, when one is to be placed in fresh water for twenty-eight days. The second pat will be placed in water which will be raised to the boiling point for six hours, then allowed to cool. Neither should show distortion or cracks. The boiling test may or may not reject at the option of the engineer officer in charge.

(10) *Time of setting.*—The cement shall not acquire its initial set in less than forty-five minutes and must have acquired its final set in ten hours.

(The following paragraph will be substituted for the above in case a quick-setting cement is desired:

The cement shall not acquire its initial set in less than twenty nor more than thirty minutes, and must have acquired its final set in not less than forty-five minutes nor in more than two and one-half hours.)

The pats made to test the soundness may be used in determining the time of setting. The cement is con-

sidered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire one-twelfth inch in diameter loaded to weigh one-fourth pound. The final set has been acquired when the pat will bear, without being appreciably indented, a wire one twenty-fourth inch in diameter loaded to weigh 1 pound.

(11) *Tensile strength.*—Briquettes made of neat cement, after being kept in air for twenty-four hours under a wet cloth and the balance of the time in water, shall develop tensile strength per square inch as follows:

After seven days, 450 pounds; after twenty-eight days, 540 pounds.

Briquettes made of 1 part cement and 3 parts standard sand, by weight, shall develop tensile strength per square inch as follows:

After seven days, 140 pounds; after twenty-eight days, 220 pounds.

(In case quick-setting cement is desired, the following tensile strengths shall be substituted for the above:

Neat briquettes: After seven days, 400 pounds; after twenty-eight days, 480 pounds.

Briquettes of 1 part cement to 3 parts standard sand: After seven days, 120 pounds; after twenty-eight days, 180 pounds.)

(12) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(13) When making briquettes well-dried cement and sand will be used; neat cement will be mixed with 20 per cent of water by weight, and sand and cement with 12½ per cent of water by weight. After being thoroughly mixed and worked for five minutes, the cement or mortar will be placed in the briquette mold in four equal layers, and each layer rammed and compressed by thirty blows of a soft brass or copper rammer three-quarters of an inch in diameter (or seven-tenths of an inch square, with rounded corners), weighing 1 pound. It is to be allowed to drop on the mixture from a height of about half an inch. When the ramming has been completed, the surplus cement shall be struck off and the final layer smoothed with a trowel held almost horizontal and drawn back with sufficient pressure to make its edge follow the surface of the mold.

(14) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under this office, bidders will deliver a sample barrel for test before the opening of bids. If this sample shows higher tests than those given above,

the average of tests made on subsequent shipments must come up to those found with the sample.

(15) A cement may be rejected in case it fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires, the engineer officer in charge may, if he deem it to the interest of the United States, have any or all of the tests made or repeated at some recognized standard testing laboratory in the manner herein specified. All expenses of such tests to be paid by the contractor. All such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.

Specifications for Natural Cement

(1) The cement shall be a freshly packed natural or Rosendale, dry, and free from lumps. By natural cement is meant one made by calcining natural rock at a heat below incipient fusion, and grinding the product to powder.

(2) The cement shall be put up in strong, sound barrels, well lined with paper so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the

name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected, or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade natural cement which have been in successful use under similar climatic conditions to those of the proposed work.)

(5) The average net weight per barrel shall not be less than 300 pounds. (West of the Alleghany Mountains this may be 265 pounds.) . . . sacks of cement shall have the same weight as 1 barrel. If the average net weight, as determined by test weighings, is found to be below 300 pounds (265 pounds) per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may

be required to supply free of cost to the United States an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, time of setting, and tensile strength of the cement.

(7) *Fineness.*—At least 80 per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) *Time of setting.*—The cement shall not acquire its initial set in less than twenty minutes and must have acquired its final set in four hours.

(9) The time of setting is to be determined from a pat of neat cement mixed for five minutes with 30 per cent of water by weight and kept under a wet cloth until finally set. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire one-twelfth inch in diameter loaded to weigh one-fourth pound. The final set has been acquired when the pat will bear, without being appreciably indented, a wire one twenty-fourth inch in diameter loaded to weigh 1 pound.

(10) *Tensile strength.*—Briquettes made of neat cement shall develop the following tensile strengths per square inch, after having been kept in air for twenty-four hours under a wet cloth and the balance of the time in water:

At the end of seven days, 90 pounds; at the end of twenty-eight days, 200 pounds.

Briquettes made of one part cement and one part standard sand by weight shall develop the following tensile strength per square inch:

After seven days, 60 pounds; after twenty-eight days, 150 pounds.

(11) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(12) The neat cement for briquettes shall be mixed with 30 per cent of water by weight, and the sand and cement with 17 per cent of water by weight. After being thoroughly mixed and worked for five minutes the cement or mortar is to be placed in the briquette mold in four equal layers, each of which is to be rammed and compressed by thirty blows of a soft brass or copper rammer three-fourths of an inch in diameter (or seven-tenths of an inch square with rounded corners), weighing 1 pound. It is to be allowed to drop on the mixture from a height of about half an inch. Upon the completion of the ramming the surplus cement shall be struck off and the last layer smoothed with a trowel held nearly horizontal and

drawn back with sufficient pressure to make its edge follow the surface of the mold.

(13) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under this office, bidders will deliver a sample barrel for test before the opening of the bids. Any cement showing, by sample, higher tests than those given must maintain the average so shown in subsequent deliveries.

(14) A cement may be rejected which fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires, the engineer officer may, if he deems it to the interest of the United States, have any or all of the tests made or repeated at some recognized standard testing laboratory in the manner above specified. All expenses of such tests shall be paid by the contractor, and all such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.

Specifications for Puzzolan Cement

(1) The cement shall be a Puzzolan of uniform quality, finely and freshly ground, dry, and free from lumps, made by grinding together without subsequent calcination granulated blast-furnace slag with slaked lime.

(2) The cement shall be put up in strong sound barrels well lined with paper, so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected, or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed, and for any brand from cement works that do not make and test the slag used in the cement.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade Puzzolan cement which have been in successful use under similar climatic conditions to those of the proposed work and which come from cement works that make the slag used in the cement.)

(5) The average weight per barrel shall not be less than 330 pounds net. Four sacks shall contain 1 barrel of cement. If the weight as determined by test weighings is found to be below 330 pounds per barrel, the cement may be rejected or, at the option of the engineer officer in charge, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, specific gravity, soundness, time of setting, and tensile strength of the cement.

(7) *Fineness.*—Ninety-seven per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) *Specific gravity.*—The specific gravity of the cement, as determined from a sample which has been carefully dried, shall be between 2.7 and 2.8.

(9) *Soundness.*—To test the soundness of cement, pats of neat cement mixed for five minutes with 18 per cent of water by weight shall be made on glass,

each pat about 3 inches in diameter and one-half inch thick at the center, tapering thence to a thin edge. The pats are to be kept under wet cloths until finally set, when they are to be placed in fresh water. They should not show distortion or cracks at the end of twenty-eight days.

(10) *Time of setting.*—The cement shall not acquire its initial set in less than forty-five minutes and shall acquire its final set in ten hours. The pats made to test the soundness may be used in determining the time of setting. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire one-twelfth inch in diameter loaded to one-fourth pound weight. The final set has been acquired when the pat will bear, without being appreciably indented, a wire one twenty-fourth inch in diameter loaded to 1 pound weight.

(11) *Tensile strength.*—Briquettes made of neat cement, after being kept in air under a wet cloth for twenty-four hours and the balance of the time in water, shall develop tensile strengths per square inch as follows:

After seven days, 350 pounds; after twenty-eight days, 500 pounds.

Briquettes made of one part cement and three parts standard sand by weight shall develop tensile strength per square inch as follows:

After seven days, 140 pounds; after twenty-eight days, 220 pounds.

(12) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(13) When making briquettes neat cement will be mixed with 18 per cent of water by weight, and sand and cement with 10 per cent of water by weight. After being thoroughly mixed and worked for five minutes the cement or mortar will be placed in the briquette mold in four equal layers and each layer rammed and compressed by thirty blows of a soft brass or copper rammer, three-quarters of an inch in diameter or seven-tenths of an inch square, with rounded corners, weighing 1 pound. It is to be allowed to drop on the mixture from a height of about half an inch. When the ramming has been completed the surplus cement shall be struck off and the final layer smoothed with a trowel held almost horizontal and drawn back with sufficient pressure to make its edge follow the surface of the mold.

(14) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under this office, bidders will deliver a sample barrel for test before the opening of bids. If this sam-

ple shows higher tests than those given above, the average of tests made on subsequent shipments must come up to those found with the sample.

(15) A cement may be rejected in case it fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires the engineer officer in charge may, if he deems it to the interest of the United States, have any or all of the tests made or repeated at some recognized testing laboratory in the manner herein specified, all expenses of such tests to be paid by the contractor. All such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.